Biochemical Characteristics of Chum Salmon Muscle during Spawning Migration*1

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The relation between gonadosomatic index (GSI) value and proximate composition of muscle of chum salmon at each migration stage did not markedly differ with the date and locality of capture. This might suggest that the situation of proximate composition can be characterized by the GSI value. The relation between GSI value and proximate composition was statistically evaluated by multiple regression analysis.

Total protein and sarcoplasmic protein contents of the muscle markedly decreased during spawning migration, while the contents of ninhydrin positive substances of non-protein nitrogenous compounds increased. A high level of muscle autolytic activity was observed in the muscle of the fish during spawning migration. The composition of muscle protein fractions at the same migratory stage did not differ greatly from fish to fish, regardless of the date and locality of capture.

Judging from the fact that proximate composition, protein composition, and autolytic activity of chum salmon muscle at the same migratory stage were almost the same regardless of the date and locality of capture, the changes described above during spawning migration were considered to be closely related to their physiological states.

In a previous paper,1) we described that the chum salmon during spawning migration can be characterized by the contents of protein, lipid, and astaxanthin in the muscle. The content of muscle lipid, particularly triglyceride, markedly decreased during the spawning migration stage,1) while that of muscle protein (sarcoplasmic protein) began to decrease during the upstream migration stage,2) i.e. after the fish entered into a river. Autolytic activity of muscle markedly rose during spawning migration.2) It was considered that these changes in the muscle compositions were closely related to the physiological states of chum salmon.3,4)

The present study was conducted to ascertain the constancy of the chemical compositions of chum salmon muscle regardless of the date and locality of capture, if the physiological states, i.e. the migratory stage, of the fish are identical.

Materials and Methods

Materials
A list of chum salmon Oncorhynchus keta at three different migratory stages used as sample is given in Table 1. Each of three male and female fish was used for the following analysis. These samples were kept at –20°C until use. Only dorsal muscle was used for the analysis.

Analytical Methods
Methods for analyses of proximate and protein compositions, SDS-polyacrylamide gel electrophoresis, and autolytic activity assay were as previously reported.1,2)

Statistical Analysis
Differences in gonadosomatic index (GSI) value and the proximate composition of each migration stage were statistically evaluated by analysis of variance.5) A relation between GSI value and the proximate composition of chum salmon muscle was also evaluated by multiple regression analysis.6)

Results

Changes of Gonadosomatic Index (GSI) Value and Proximate Composition
Fig. 1 shows the comparison of GSI value and the proximate composition between two groups of chum salmon at the feeding migration stage. Respective measurements were shown by F-test not to differ greatly between two groups of the
Table 1. Details of chum salmon used as sample

<table>
<thead>
<tr>
<th>Stage</th>
<th>Date and locality of capture</th>
<th>Sex</th>
<th>Body length*1 (cm)</th>
<th>Body weight*1 (g)</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding migration</td>
<td>June 11–July 31, 1982.</td>
<td>Male</td>
<td>53</td>
<td>2540</td>
<td>03-04</td>
</tr>
<tr>
<td></td>
<td>Lat. 42°27'N–47°27'N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lon. 154°30'E–154°50'E</td>
<td>Female</td>
<td>56</td>
<td>2910</td>
<td>03-04</td>
</tr>
<tr>
<td></td>
<td>Aug. 1–6, 1983.</td>
<td>Male</td>
<td>43</td>
<td>1370</td>
<td>02-04</td>
</tr>
<tr>
<td></td>
<td>Lat. 45°59'N–49°29'N</td>
<td>Female</td>
<td>47</td>
<td>1590</td>
<td>03</td>
</tr>
<tr>
<td></td>
<td>Lon. 167°07'E–175°30'E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shibetsu coast of Hokkaido</td>
<td>Female</td>
<td>64</td>
<td>3660</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Nov. 4, 1982.</td>
<td>Male</td>
<td>66</td>
<td>3810</td>
<td>03-04</td>
</tr>
<tr>
<td></td>
<td>Moheji coast of Hokkaido</td>
<td>Female</td>
<td>68</td>
<td>4540</td>
<td>03-05</td>
</tr>
<tr>
<td></td>
<td>Oct. 21, 1983.</td>
<td>Male</td>
<td>63</td>
<td>3270</td>
<td>03</td>
</tr>
<tr>
<td></td>
<td>Yakunoo coast of Hokkaido</td>
<td>Female</td>
<td>64</td>
<td>3570</td>
<td>03</td>
</tr>
<tr>
<td>Upstream migration</td>
<td>Nov. 6, 1980.</td>
<td>Male</td>
<td>69</td>
<td>4180*2</td>
<td>04</td>
</tr>
<tr>
<td></td>
<td>Lower reaches (8 km) of Kushiro River, Hokkaido</td>
<td>Female</td>
<td>66</td>
<td>3370*2</td>
<td>04</td>
</tr>
<tr>
<td></td>
<td>Lower reaches (4 km) of Oirase River, Aomori Prefecture</td>
<td>Female</td>
<td>65</td>
<td>2630*3</td>
<td>04</td>
</tr>
<tr>
<td></td>
<td>Nov. 4, 1982.</td>
<td>Male</td>
<td>66</td>
<td>3780</td>
<td>03</td>
</tr>
<tr>
<td></td>
<td>Lower reaches (0.2 km) of Moheji River, Hokkaido</td>
<td>Female</td>
<td>70</td>
<td>3490*3</td>
<td>03</td>
</tr>
<tr>
<td></td>
<td>Nov. 25, 1983.</td>
<td>Male</td>
<td>78</td>
<td>6540</td>
<td>04</td>
</tr>
<tr>
<td></td>
<td>Lower reaches (1.8 km) of Yurappu River, Hokkaido</td>
<td>Female</td>
<td>70</td>
<td>5130</td>
<td>03-04</td>
</tr>
</tbody>
</table>

*1 Average of three fish.
*2 Weight of semi-dressed fish.
*3 Weight of the fish from which gonad was removed.

Fig. 1. Comparisons of gonadosomatic index (GSI) value and muscle proximate composition between two groups at the feeding migration stage of male (●) and female (○) chum salmon. The vertical bars represent the mean ± S. D. of three fish. 1, Fish captured in 1982; II, fish captured in 1983. *Not significant; bP<0.05; cP<0.025; dP<0.01.
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Fig. 2. Comparisons of gonadosomatic index (GSI) value and muscle proximate composition among three groups at the spawning migration stage of male (●) and female (○) chum salmon (refer to the legend in Fig. 1). I, Fish captured at Shibetsu coast of Hokkaido in Oct. 19–Nov. 17, 1976; II, fish captured at Moheji coast of Hokkaido in Nov. 4, 1982; III, fish captured at Yakumo coast of Hokkaido in Oct. 21, 1983.

Fig. 3. Comparisons of gonadosomatic index (GSI) value and muscle proximate composition among four groups at the upstream migration stage of male (●) and female (○) chum salmon (refer to the legend in Fig. 1). I, Fish captured at lower reaches (8 km) of Kushiro River, Hokkaido in Nov. 6, 1980; II, fish captured at lower reaches (4 km) of Oirase River, Aomori Prefecture in Jan. 23–26, 1982; III, fish captured at lower reaches (0.2 km) of Moheji River, Hokkaido in Nov. 4, 1982; IV, fish captured at lower reaches (1.8 km) of Yurappu River, Hokkaido in Nov. 25, 1983.
fish, with an exception of those of protein composition. Fish with a high level of lipid content was found in the female fish.

Fig. 2 shows the results of comparison of GSI value and proximate composition of three groups of chum salmon caught in the different years at the spawning migration stage. Almost the same patterns were shown among three groups, except for protein and extractive nitrogen contents. The GSI values of the female fish were markedly elevated compared with those of male.

Fig. 3 shows the results of comparison of GSI value and proximate composition of four groups of chum salmon at the upstream migration stage. Respective measurements also did not differ greatly among four groups of the sample fish, except for extractive nitrogen content.

**Changes in Protein Composition**

Fig. 4 shows the difference in muscle protein composition of chum salmon during spawning migration. No noticeable difference was found between protein composition of samples captured in 1982 and those in 1983. The fish captured at the feeding migration stage showed high contents of total protein and sarcoplasmic protein, and low levels of ninhydrin positive substances in non-protein nitrogenous compounds. Ninhydrin positive substances were found to increase in the amount during the spawning migration stage. The fish captured at the upstream migration stage showed low levels of total protein and sarcoplasmic protein, and high levels of ninhydrin positive substances.

No noticeable difference of SDS-polyacrylamide gel electrophoretograms of muscle protein fractions was seen between the samples captured in 1982 and those in 1983 (Fig. 5). It is apparent from the electrophoretograms that myosin heavy chains were degraded during spawning migration.

![Fig. 4](image)

**Fig. 4.** Changes in muscle protein composition of chum salmon during spawning migration.
---, Fish captured in 1982; -----, fish captured in 1983.

![Fig. 5](image)

**Fig. 5.** SDS-slab-polyacrylamide gel (10%) electrophoretic patterns of muscle protein fractions of male (M) and female (F) chum salmon during spawning migration. (A), Fish captured in 1982; (B), fish captured in 1983.
Changes in Autolytic Activity

Fig. 6 shows the comparison of muscle autolytic activity of chum salmon, which were captured in 1982 and 1983, during spawning migration. Each curve of autolytic activity of the samples captured in 1982 and those in 1983 was essentially the same. The autolytic activity at around pH 3 markedly increased during spawning migration. Autolytic activity at pH 6 was also observed to increase gradually during spawning migration, maybe corresponding to the change of physiological states.

Discussion

The results of the present study have demonstrated the constancy of the chemical compositions of chum salmon muscle regardless of the date and locality of capture, if the migratory stage of the fish were identical.

As shown in Figs. 1, 2 and 3, GSI value and muscle proximate composition of each migration stage did not significantly change, which was statistically evaluated by F-test, regardless of the date and locality of capture. Fig. 7 summarized various data obtained from the fish at each migration stage. Almost the same tendency as described in a previous paper was obtained. It was therefore concluded that muscle composition of chum salmon during spawning migration was characteristic of each migration stage. GSI values of females were markedly elevated during their spawning migration stage, and high values were maintained during their upstream migration stage. In contrast, the GSI values of male fish slightly increased during the spawning migration stage. The lipid content markedly decreased during the spawning migration stage, while the protein content markedly decreased during the upstream migration stage. This might suggest that muscle lipid was firstly utilized as energy source for the development of the gonads and thereafter muscle protein was utilized as energy source for upstream migration. Extractive nitrogen slightly increased in the contents during spawning migration. Astaxanthin and "a" value (an index of redness in muscle color) of muscle markedly decreased at the upstream migration stage.

Considering the above changes in muscle composition of chum salmon during spawning migration, the proximate composition can be presumed by the GSI value. Therefore, we attempted to discuss statistically the relation between GSI value and proximate composition with multiple re-
gression analysis. The relation was expressed as follows:

\[ Y = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \beta_3 \cdot X_3 + \beta_4 \cdot X_4 + \beta_5 \cdot X_5 + \beta_6 \cdot X_6 + \beta_7 \cdot X_7 + e \]

where \( Y \) is GSI value, \( X_1 \) moisture content, \( X_2 \) ash content, \( X_3 \) lipid content, \( X_4 \) protein content, \( X_5 \) extractive nitrogen content, \( X_6 \) astaxanthin content, \( X_7 \) "a" value, \( \beta_j \) (\( j = 0, 1, 2, 3, 4, 5, 6, 7 \)) partial regression coefficient, and \( e \) residuals.

The relation between GSI value and proximate composition of male fish was expressed by the equation (1).

\[ Y = 0.35 \cdot X_1 + 1.33 \cdot X_2 - 1.66 \cdot X_3 - 0.73 \cdot X_4 + 3.36 \cdot X_5 + 1.47 \cdot X_6 - 0.05 \cdot X_7 - 37.99 \]  

The relation between measured GSI values and GSI values induced by the above equation (1) was shown in Fig. 8(A). The relation was significant at 2.5% level. The relation between GSI value and proximate composition of female fish was represented by the equation (2).

\[ Y = 2.97 \cdot X_1 + 5.27 \cdot X_2 - 1.31 \cdot X_3 + 3.60 \cdot X_4 + 48.56 \cdot X_5 + 15.82 \cdot X_6 - 0.90 \cdot X_7 - 302.14 \]

The relation between measured GSI values and GSI values induced by the above equation (2) was shown in Fig. 8(B). The relation was significant at 2.5% level. As described above, it was confirmed that the changes in muscle compositions of chum salmon during spawning migration can be
characterized by the GSI value.

Almost the same results were found between protein composition of samples captured in 1982 and those in 1983. Total protein and sarcoplasmic protein markedly decreased, while ninhydrin positive substances of non-protein nitrogenous compounds increased during spawning migration. The degradation of myosin heavy chains was clearly detected by SDS-polyacrylamide gel electrophoresis. The changes in muscle protein composition might suggest that sarcoplasmic protein as well as myofibrillar protein was utilized as energy source of upstream migration.

No noticeable difference was found between autolytic activity of samples at the same migratory stage captured in 1982 and those in 1983. Autolytic activities of both fish markedly increased during spawning migration. Konagaya8,9) has reported that muscle autolytic activity markedly increased during spawning migration. It was therefore proved that high levels of autolytic activity of the muscle during spawning migration were undoubted facts. High levels of protease activity might be necessary to the utilization of muscle protein as energy source to ascend the river.

Judging from the fact that proximate composition, protein composition, and autolytic activity of chum salmon muscle at the same migratory stage did not differ with the date and locality of capture, it was concluded that the changes of the muscle composition occurring during spawning migration were, as described above, closely related to their physiological states, i.e. the degree of maturation.

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References